TURBINE BLADE TIP AND OUTER AIRSEAL FLOW ANALYSIS WITH STRUCTURED AND UNSTRUCTURED CODES

Chunill Hah
NASA Lewis Research Center
Cleveland, Ohio

Dr. Chunill Hah will be talking about recent work to develop area of analyzing blade tip seals and outer air seals which are very important in trying to minimize efficiency loss in this area.

We have developed a numerical tool to simulate this type of program. This shows the single HP turbine including the cooling passages. Since the rotor blade geometry is actually rotating, the pressure field is unsteady. We have shown in certain cases the cooling flow is coming out of the rim and when the pressure near the hub becomes high, the cooling flow will go backward into the rim seal. The existence of this complex feature in the flow field is the motivation for developing this numerical tool and Bill Daniels (UTRC) will present some experimental data. The goal is to compare the numerical solution to the experimental data.

There are many 3-D unsteady structured codes, but for complicated system such as the cooling passage, unstructured codes might be much easier for designers to use. We could couple structured and unstructured solutions, but it might be easier for designers to just use the unstructured grid for the entire domain. The unstructured code was used for SSME applications where it was found that it is very tricky to grid geometries such as volute using structured-grid codes.

What I'd like to do is show that the code has been pretty much developed and we are waiting for some experimental data coming out so we can compare the two. I will not go into details, but the code is based on well developed unstructured method originally developed at Langley for external flow fields. We have modified it for internal flow field and implemented latest technology as far as unstructured method is concerned. For this type of flow field, we also have two turbulence model in the code. This shows the unsteady pressure envelope near the tip, mid-span, and the hub, and here we have the time average static pressure data and it looks like it is getting reasonable results as far as pressure field is concerned.

As I've mentioned, for this case we are looking for the interaction between the pressure field with the cooling flow injection. We are also looking at gap clearance and will have 10 mil and 6 mil cases to see what effect it has on the flow field. And finally, we did calculation for the isolated rim seal geometry and have obtained solution for this problem to study the effect of external pressure field on inside the rim seal.

Questions

Q. Two component, axial mass flow and leakage are monitored so you can determine the injections taking place?

A. Yes. Bill Domiels will adjust the pressure in the coolant - so we want to see how accurately, numerically we can simulate the leakage for that test.

Q. You have the stator, rotor, and the cavity. All three, one shot computation?

A. Yes. We solve them altogether.

Q. Altogether? And then you looking at aspiration mixing flow?

A. Yes. A steady flow is run at the beginning, then the solution is marched time accurately to include blade rotation effects and obtain the true unsteady flow field.

UNSTRUCTURED FLOW SOLVER

- Based on USM3D unstructured solver

- Cell-based finite volume method

- Implicit Euler time integration

- Second-order Advection Upstream Splitting Method (AUSM) for inviscid flux calculation

- Viscous flux terms computed with second-order reconstruction in a centered manner

- Turbulence closure via Spalart-Allmaras model

- Characteristic boundary conditions at inlet and exit, wall function on solid surfaces

- Node-based finite volume method

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POSSIBLE TURBOMACHINERY APPLICATIONS

- Turbine cooling flows

- Turbine volutes

- Centrifugal compressor stages

Mach Number Contour on Oxidizer Turbine Rotor
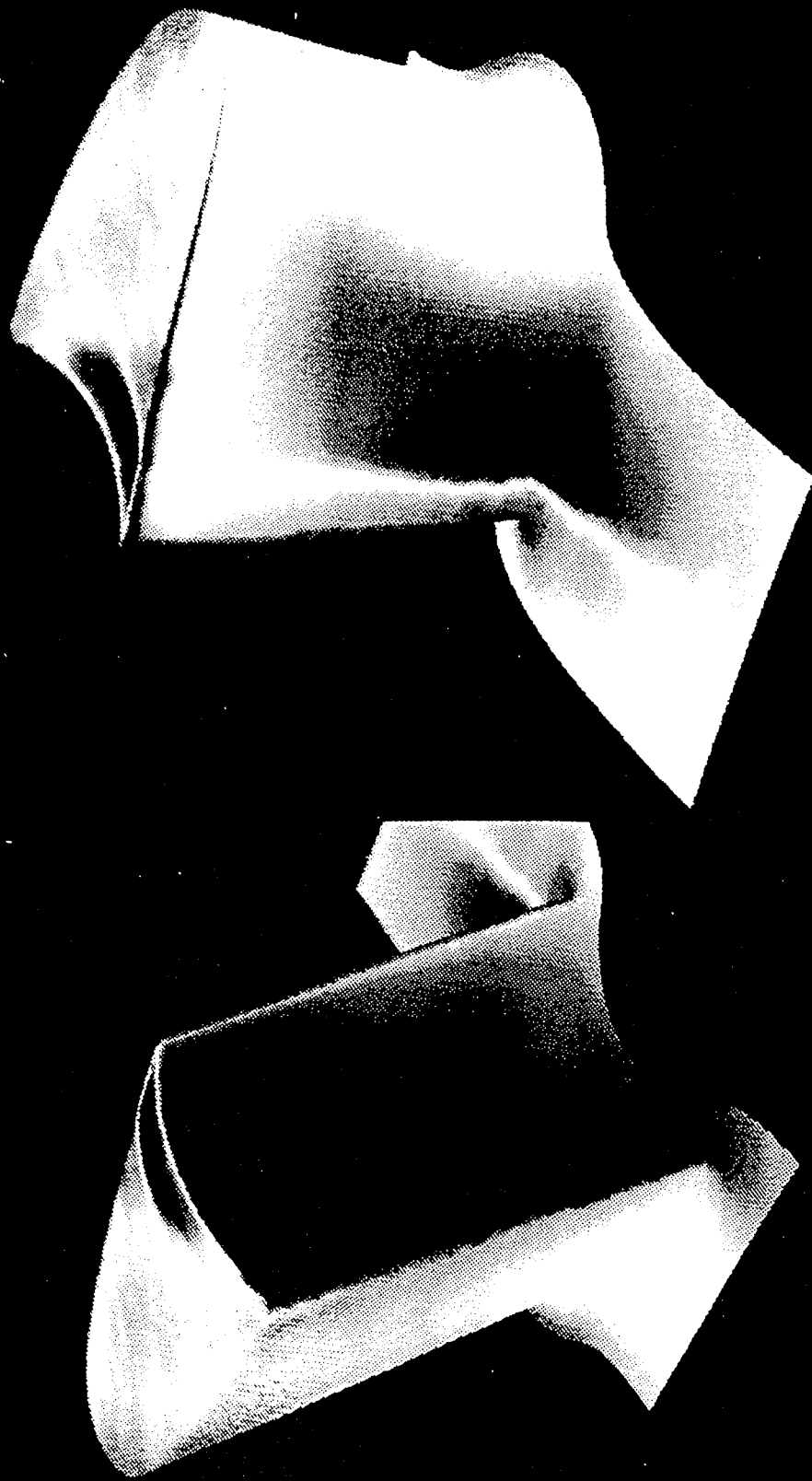
1.176
1.064
1.008
0.952
0.896
0.840
0.784
0.728

Velocity Vectors Near Outer Wall
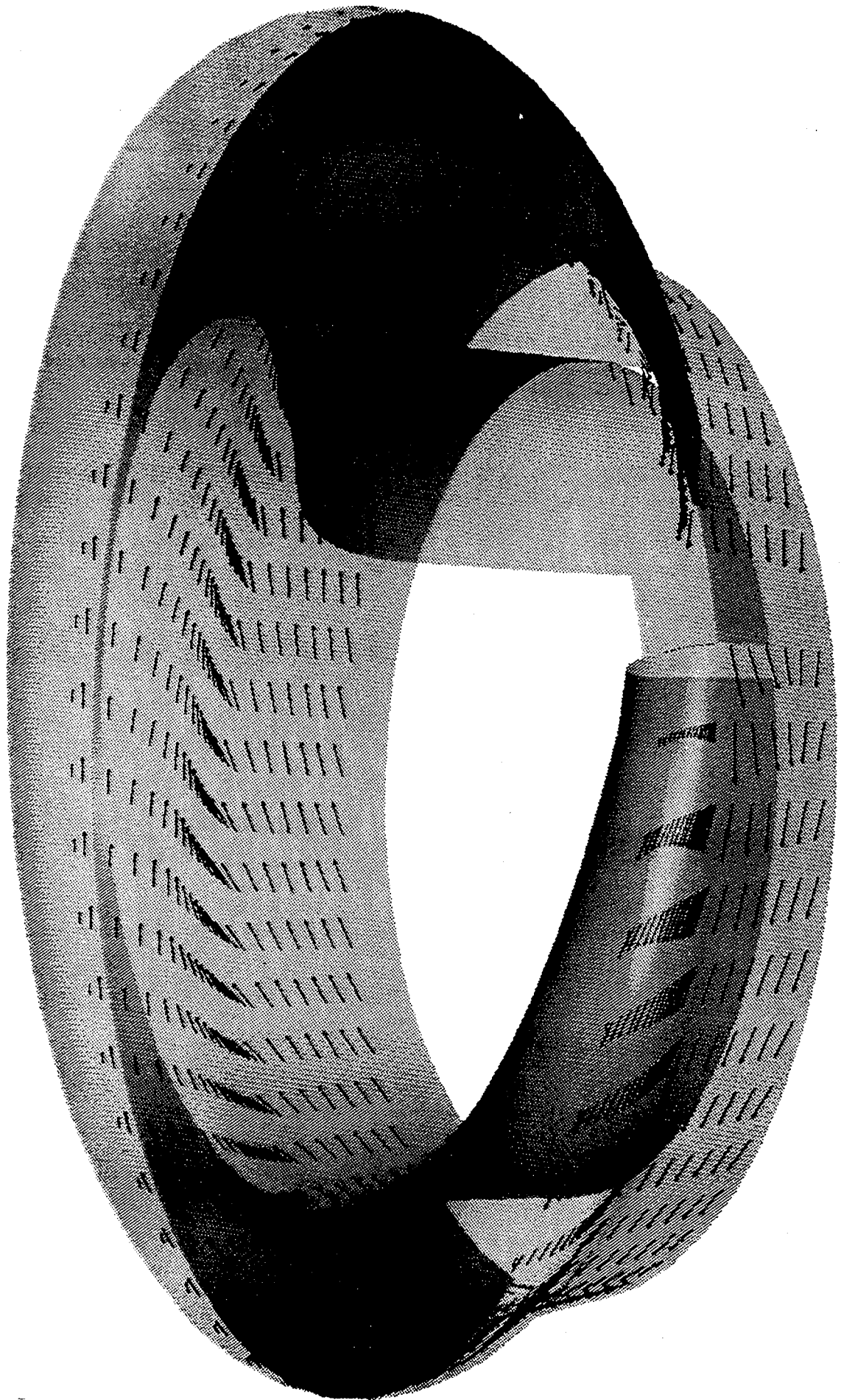
Velocity Vectors Near Inner Wall
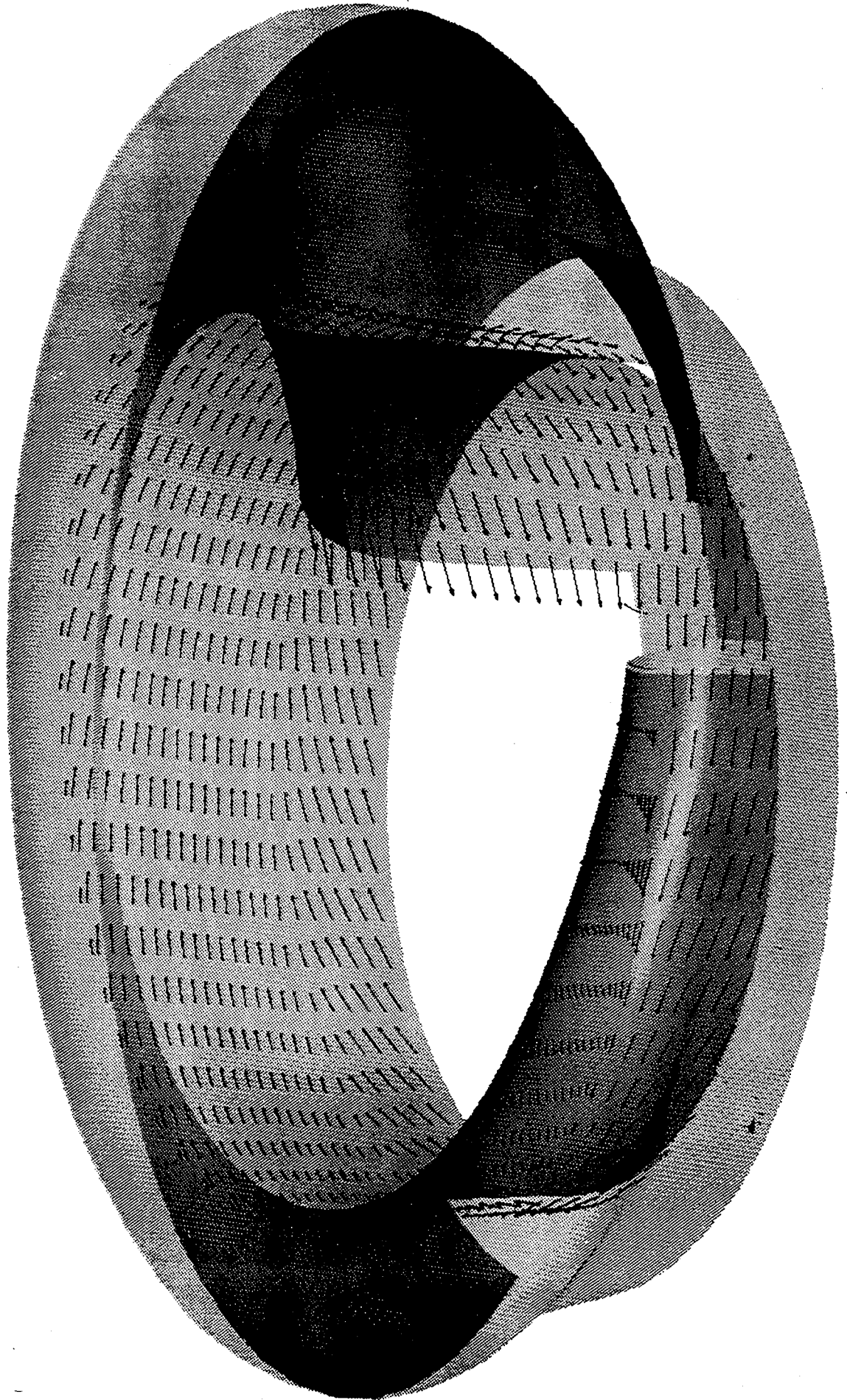
SCHEMATIC OF TURBINE STAGE EXPERIMENT

UPSTREAM THERMOCOUPLES

REDESIGNED FRAME

COOLANT INFUSION COUPLING

BLADE

VANE

STRUTS

FLOW

CENTERLINE
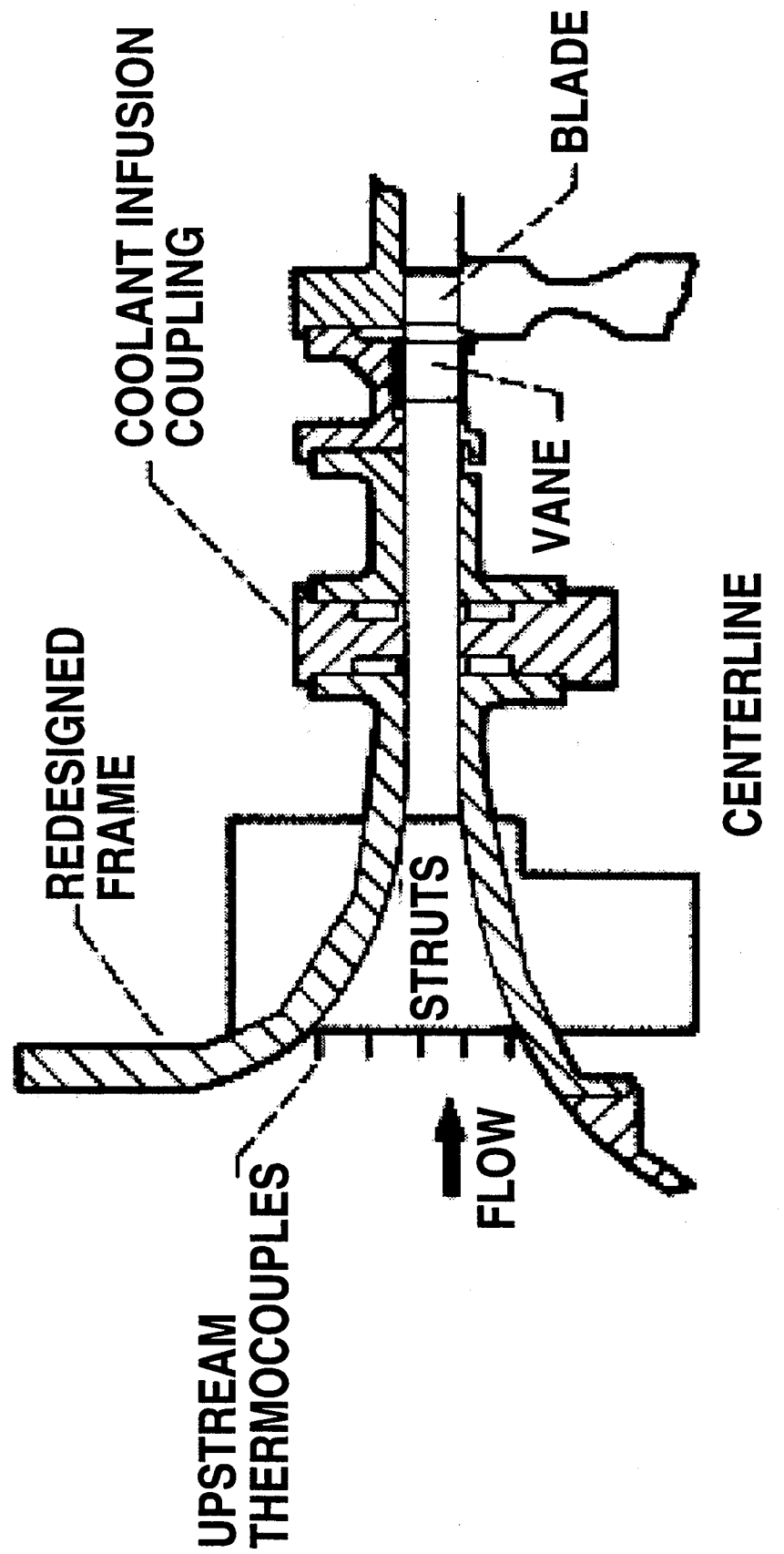
COMPUTATIONAL GRID
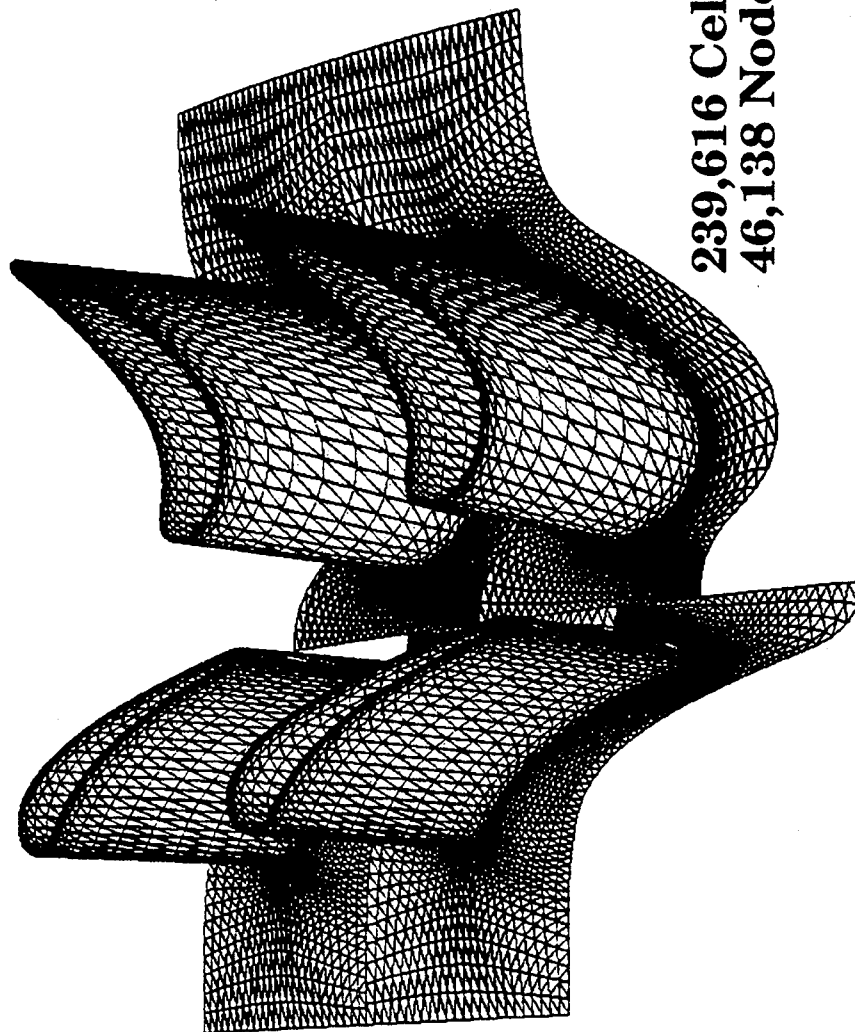
239,616 Cells
46,138 Nodes

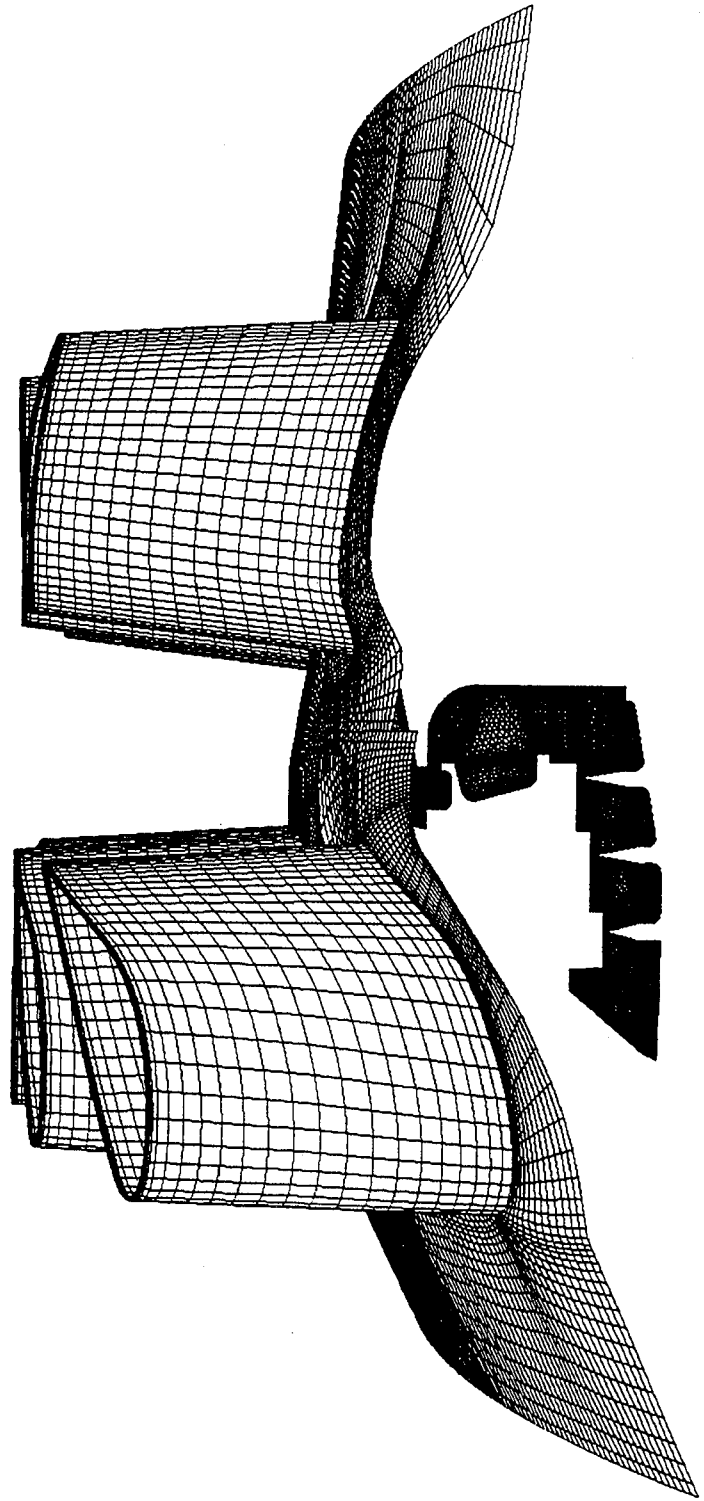INSTANTANEOUS PRESSURE CONTOURS
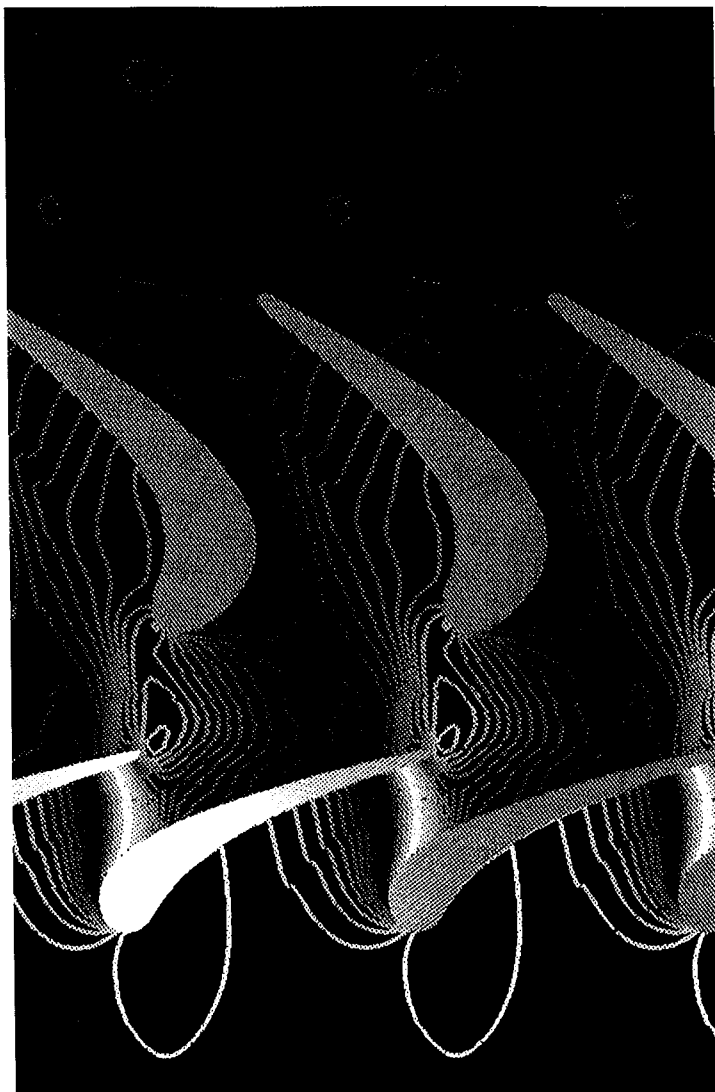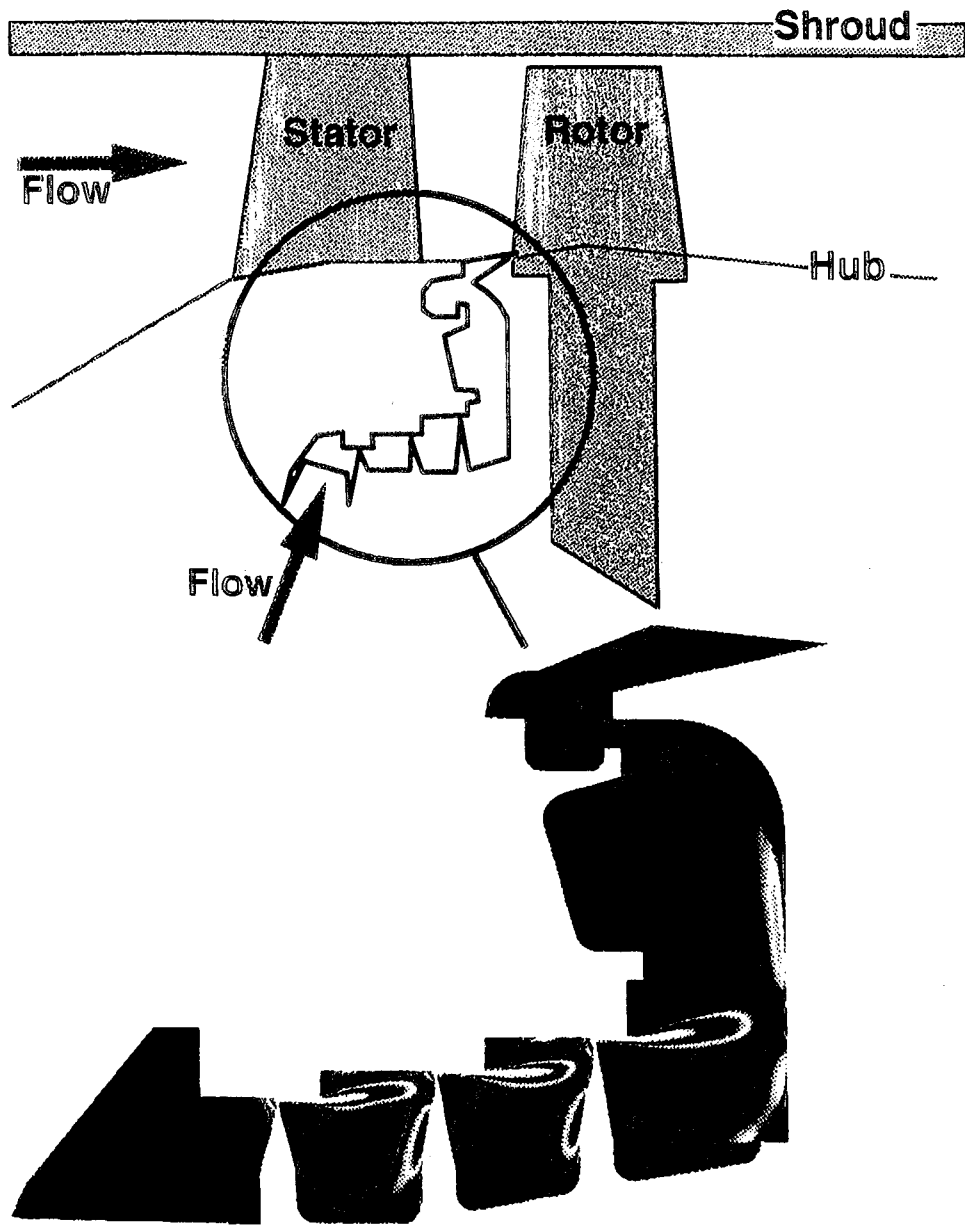
RESULTS - TURBINE STAGE
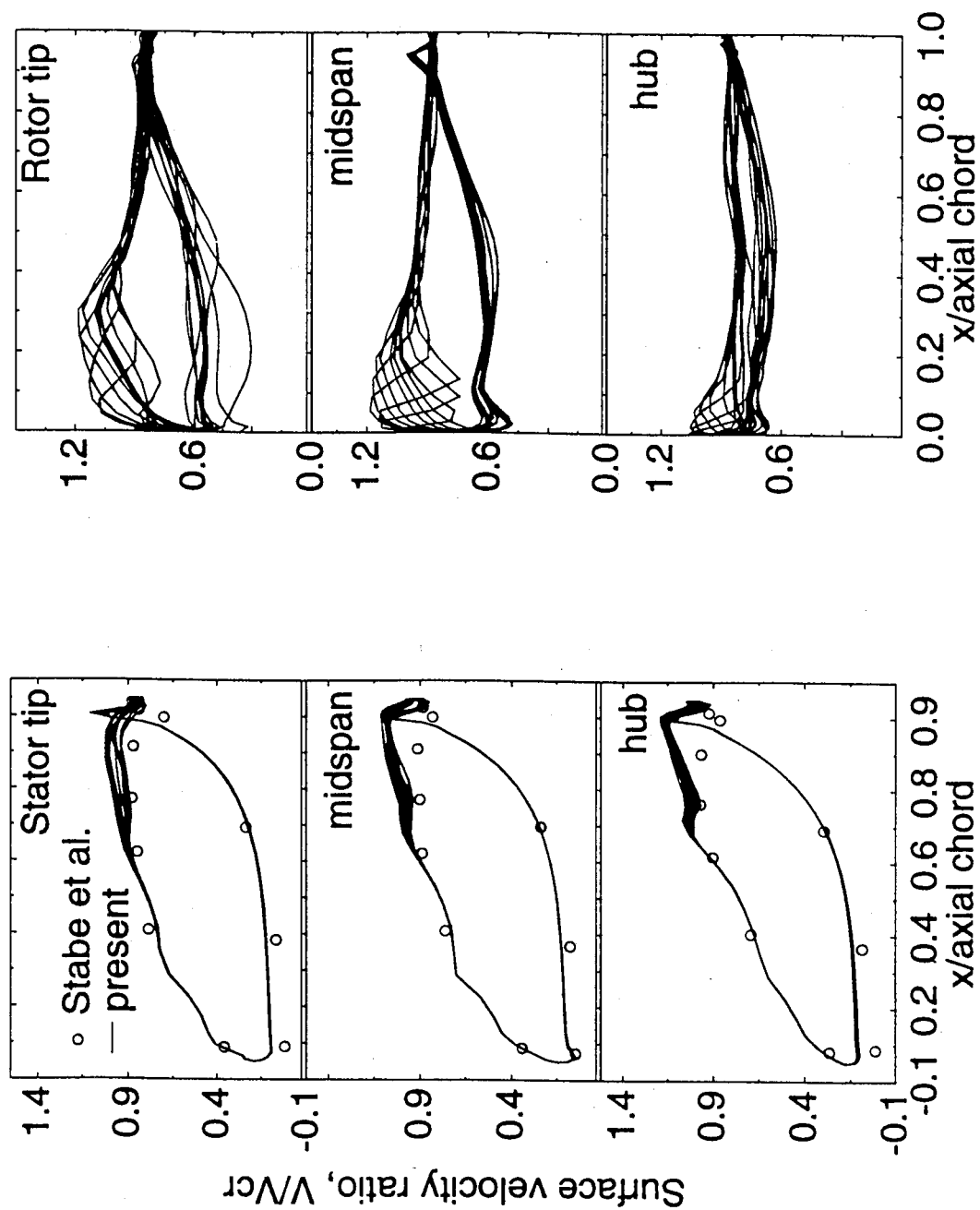
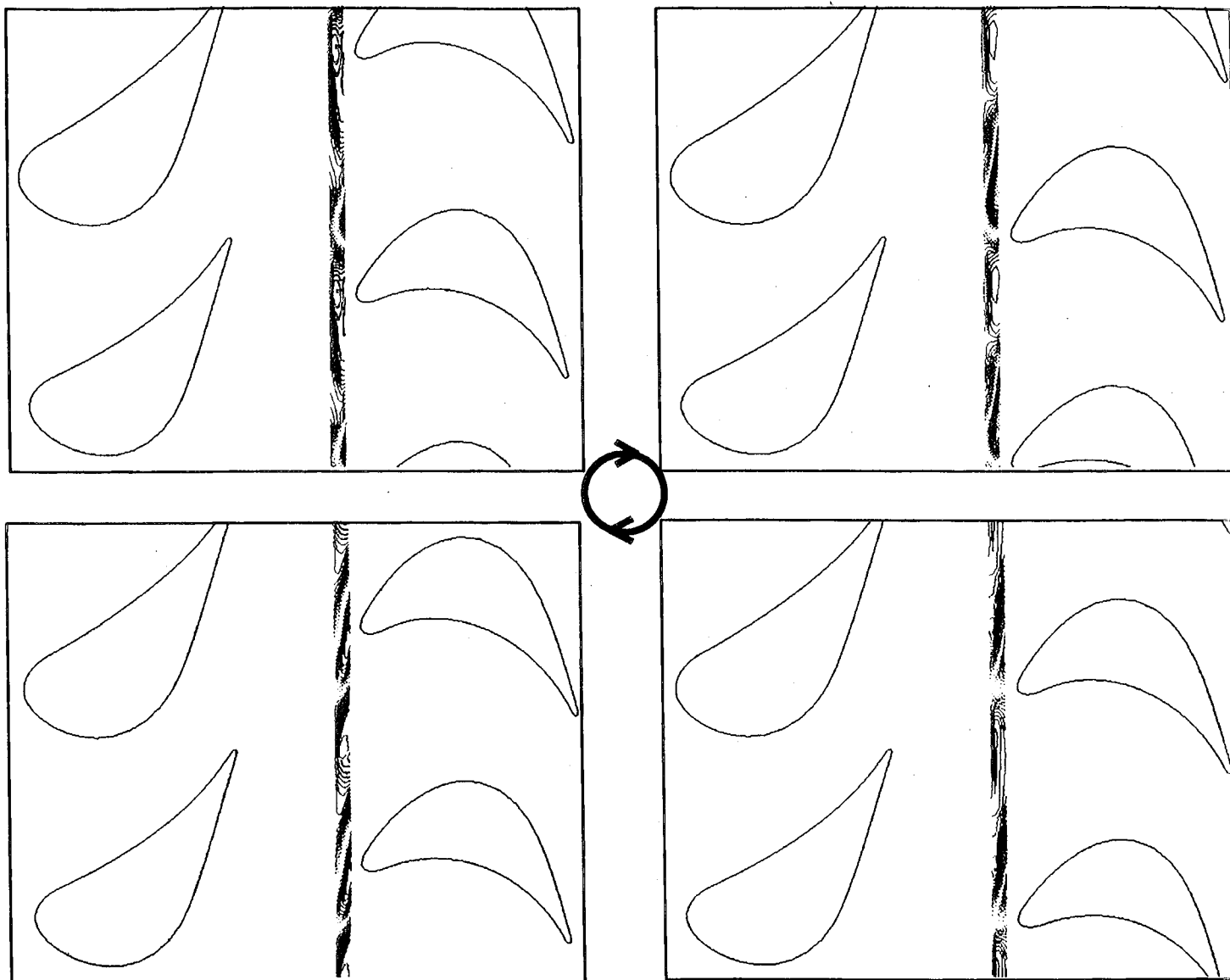# RESULTS - TURBINE STAGE

Unsteady pressure coefficient at midspan
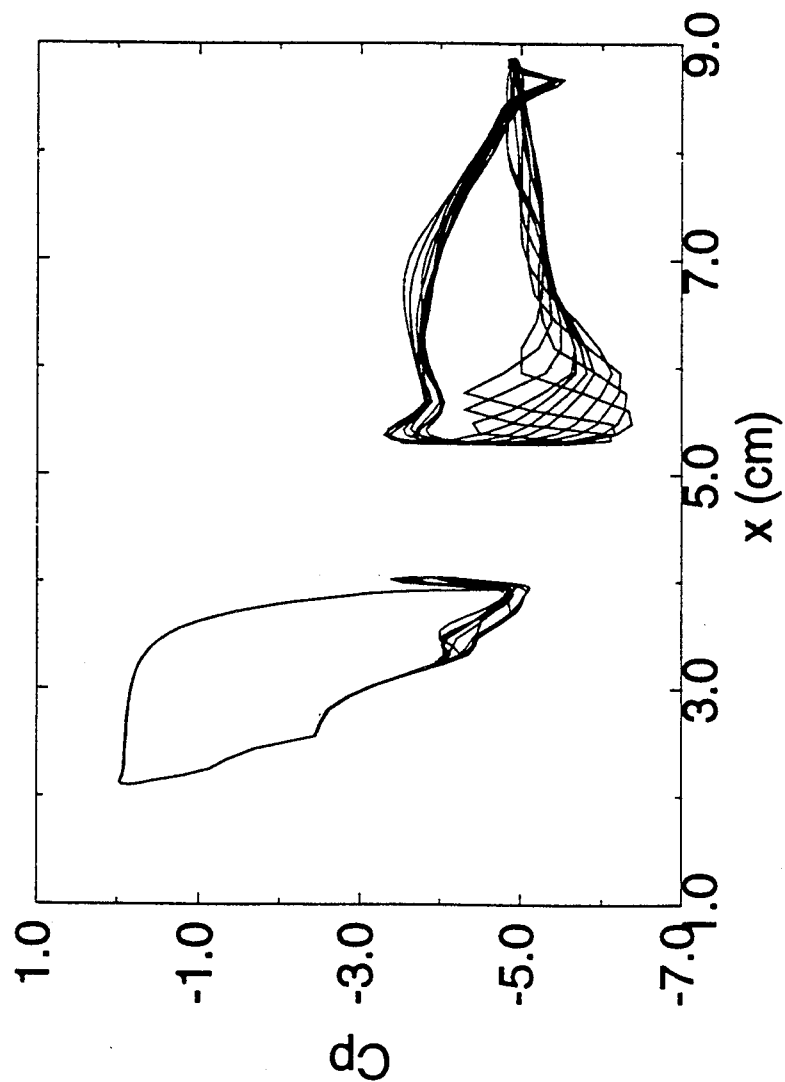
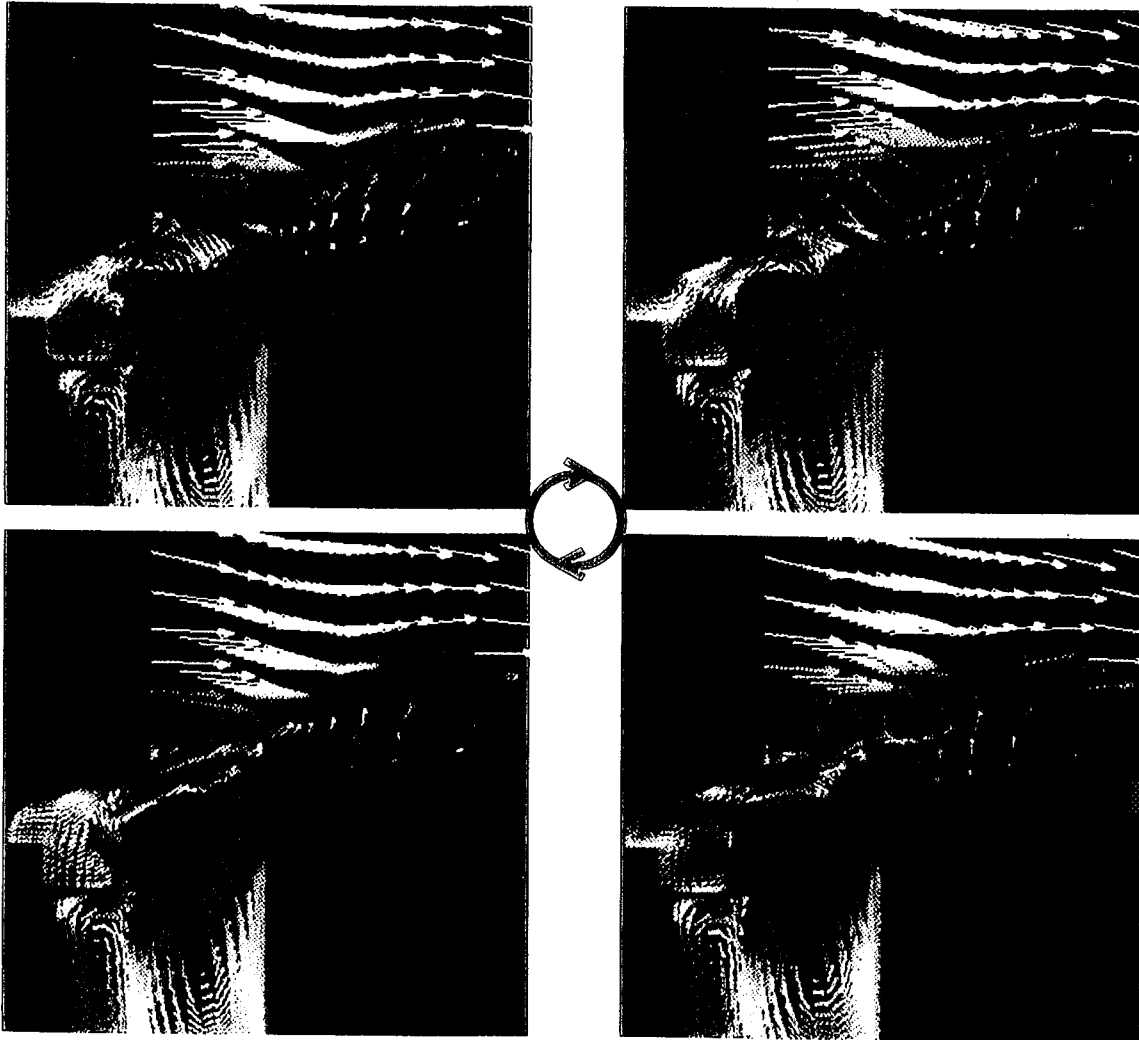Combined Turbine Stage and Rim Seal Grids

Instantaneous distribution of Mach number.

Instantaneous contours of radial velocity.

Instantaneous velocity vectors.